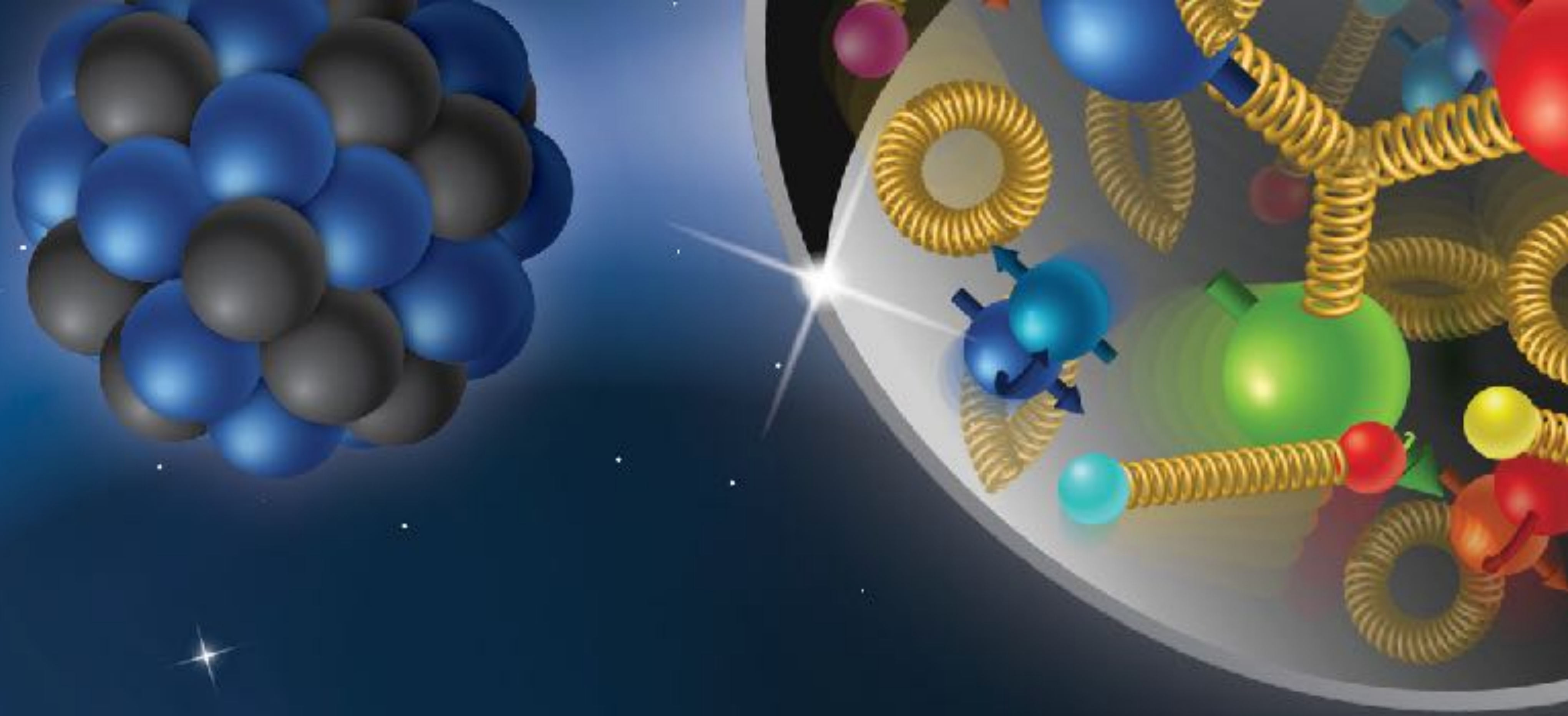

eRHIC Science Case - Overview

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eRHIC Science Case Review
March 2, 2017

eRHIC: Electron Ion Collider

BROOKHAVEN NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY | Office of Science

NAS Panel charge

The committee will assess the scientific justification for a U.S. domestic electron ion collider facility, taking into account current international plans and existing domestic facility infrastructure. In preparing its report, the committee will address the role that such a facility could play in the future of nuclear physics, considering the field broadly, but placing emphasis on its potential scientific impact on quantum chromodynamics.

In particular, the committee will address the following questions:

- What is the merit and significance of the science that could be addressed by an electron ion collider facility and what is its importance in the overall context of research in nuclear physics and the physical sciences in general?
- What are the capabilities of other facilities, existing and planned, domestic and abroad, to address the science opportunities afforded by an electron-ion collider? What unique scientific role could be played by a domestic electron ion collider facility that is complementary to existing and planned facilities at home and elsewhere?
- What are the benefits to U.S. leadership in nuclear physics if a domestic electron ion collider were constructed?
- What are the benefits to other fields of science and to society of establishing such a facility in the United States?

NAS Panel Membership

Ani Aprahamian (Notre Dame - *co-chair*)
Gordon Baym (UIUC - *co-chair*)

Christine Aidala (U Michigan)
Haiyan Gao (Duke U)
Kawtar Hafidi (ANL)
Larry McLerran (U Washington)
Zein-Eddine Meziani (Temple U)
Richard Milner (MIT)
Ernst Sichtermann (LBNL)

Peter Braun-Munzinger (GSI - *heavy ion physics*)
Wick Haxton (UC Berkeley - *neutrino physics*)
John Jowett (CERN - *accelerator science*)
Thomas Schaefer (NC State - *many-body physics & QCD*)
Michael Turner (U Chicago - *cosmology*)

NAS Study Risks

- **NAS Panel composition has been made public:**
  - Co-chairs: Gordon Baym & Ani Aprahamian
  - Most other members are EIC proponents
  - First panel meeting February 1-2, 2017
- **List of panel members makes positive recommendation likely**
- **What are the risks?**
  - EIC is Recommendation #3 in the LRP after $0\nu\beta\beta$ decay (Haxton)
  - Scientific claims may be viewed as exaggerated (Turner)
  - The higher energy offered by eRHIC may not be viewed as a priority
  - Designs concepts may be deemed immature and too risky (Jowett)
- **How we plan to address these risks:**
  - EIC and $0\nu\beta\beta$ decay are not competing in the same sphere
  - Clearly state our science claims but be careful not to exaggerate them
  - Work out a strong case why the higher eRHIC energy is a game changer
  - Present a design that has no obvious show stoppers and is affordable

EIC “Elevator” Speech (version 1)

Protons and neutrons are the fundamental building blocks of the nuclei found in atoms. Called nucleons, they collectively comprise more than 99% of the mass of all visible matter in the universe, including stars, planets, and people.

In spite of their importance, we know less about the internal structure of nucleons than about any other component of matter. We know that nucleons are composed of even more fundamental particles—quarks and gluons. These are the smallest building blocks of visible matter, but all we have been able to establish so far is a crude one-dimensional picture of how they are distributed in a moving proton.

Next to black holes, nucleons are the most curious objects we know. Just like nothing can escape from a black hole, quarks cannot escape from a nucleon, although they rattle around inside them at nearly the speed of light. And in contrast to black holes, which hide in the depth of the universe, nucleons are present in our own bodies in myriad numbers.

Our limited knowledge of the nucleon’s internal structure means that we do not understand something as fundamental as the origin of the proton’s mass, nor of its intrinsic magnetism, called “spin.” These are 100-year old questions in science.

Gluons—the particles that bind quarks together—are suspected to lie at the origin of all these unusual properties, yet we have very limited experimental information that tells us how gluons interact and build nucleons and nuclei. The EIC will provide these data and help close this gap in our understanding of the world in an around us.

EIC “Elevator” Speech (version 2)

Protons and neutrons are, with electrons, the fundamental building blocks of the atom. Called nucleons, protons and neutrons comprise more than 99% of the mass of the visible matter of the universe, including stars, planets, and everything in our earthly environment including all living beings.

A search for a deep understanding of the internal structure of the nucleons is a fundamental goal of nuclear physics, one that could provide insights into the basic structure of matter and, through the technologies develop to carry out this search, reap substantial benefits for society.

We know that nucleons are composed of even more fundamental particles, quarks and gluons. These are the smallest building blocks of everyday matter, but we do not yet have a clear and detailed idea of how quarks and gluons come together to form and give structure to nucleons.

As a result of recent developments in theoretical nuclear physics and immerging capabilities to control and collide very energetic beams of particles, an important scientific opportunity lies ahead of us. With the construction of a state-of-the-art electron-ion collider (the EIC), scientists will be able to understand how the underlying structure of nucleons gives ordinary matter the characteristics that form the material world around us.

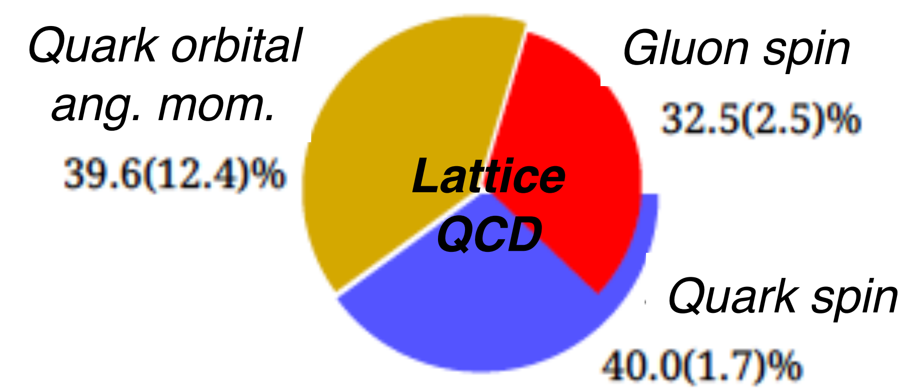
Specific “Big” Questions

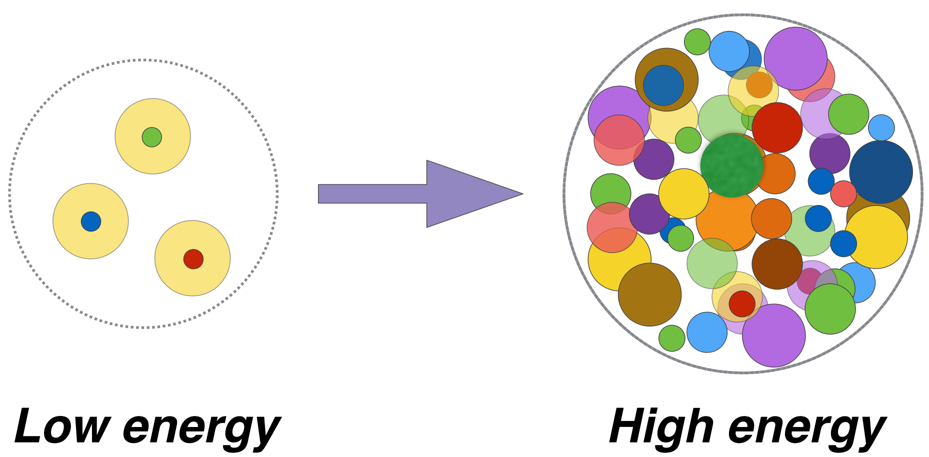
Proton spin:

Quark spin contributes only ~30% to the proton’s spin

How do quark and gluon dynamics generate the remainder of the proton’s spin?

The EIC will definitively resolve this question.





Gluon saturation:

Gluons proliferate at high energy (small Bjorken-x)

How does the gluon density saturate to avoid violation of fundamental principles like unitarity?

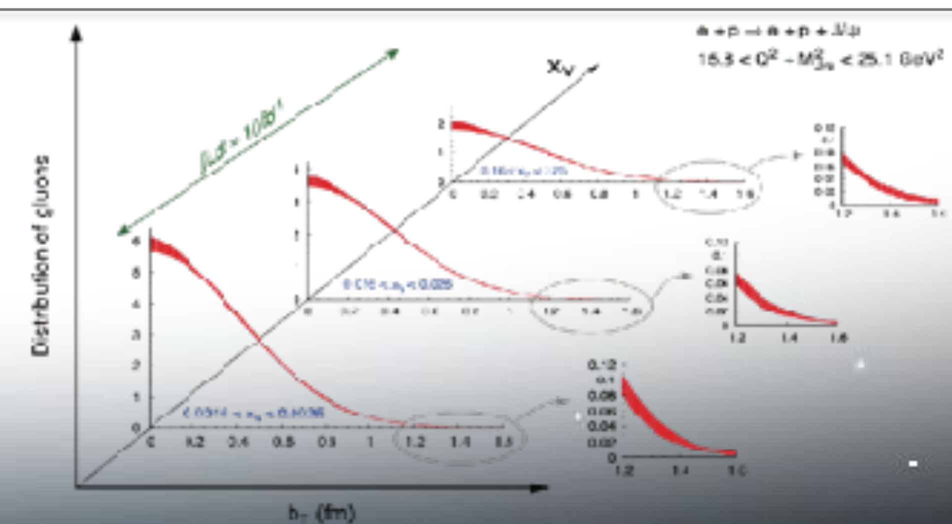
The EIC will explore this question using heavy nuclei.

Proton transverse structure:

We know the 1-D (longitudinal) structure of a moving proton very well

What does the proton look like in 3 dimensions?

The EIC will definitively answer this question.



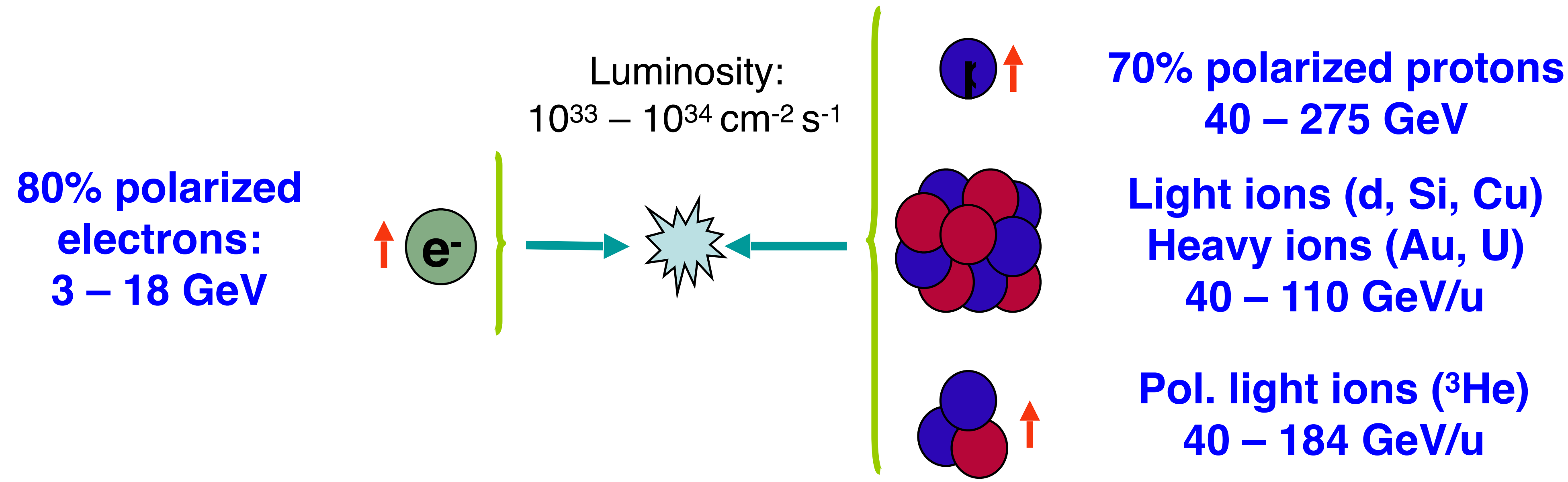
EIC science case

- **Must be explained to a broad range of audiences:**
  - *Non-QCD physicists, non-physicists, non-scientists*
  - *How much should we care about the internal structure of p & A?*
  - *The proton (nucleon) is the last component of ordinary matter whose internal structure is not well understood ("the final frontier")*
- **Connect measurements to simple ideas and concepts**
- **EIC needs a rich 20+ year program**
  - *Compelling physics at increasing levels of precision*
- **Potential for discovering unexpected phenomena and physics alluring to a broader audience must be emphasized**
  - *RHIC physics program is a good role model*
  - *Heavy nuclei and polarization open entirely new regimes*
- In development:
  - *Table of specific requirements for measurements - e.g. detector acceptance, particle ID, integrated luminosity, background issues*
  - *Science program and deliverables for first 5 years*

Design considerations

- **√s range: As large as possible for extended reach in x and Q^2**
  - √s(ep) > 100 GeV required for gluon saturation physics and gluon imaging
  - √s(ep) > 100 GeV needed to reduce error in spin contributions from small x
- **Full nuclear coverage in *A***
  - "Oomph" factor: Effective x-range of saturation extends to 200-times smaller x
- **Luminosity: Large but realistic**
  - Initial L ≈ 10^{33} $cm^{-2}s^{-1}$ (or ∫dt L ≈ 10 fb^{-1}/yr) enables compelling science:
    - Definitive proton spin decomposition measurement
    - Gluon and sea-quark distributions in nuclei
    - Gluon saturation versus *A*
    - Precise imaging of unpolarized quark & gluon distributions in position and momentum space (GDPs and TMDs)
  - Full luminosity L ≈ 10^{34} $cm^{-2}s^{-1}$ (or ∫dt L ≈ 100 fb^{-1}/yr) covers the full physics program described in the EIC White Paper
- **Beam divergence in IR:**
  - Small divergence at IR required to resolve small angle (diffractive) scattering

Primary eRHIC Design Goals



Maximum Peak Luminosity	$\geq 10^{34}$ cm^{-2}s^{-1}
Accepted Luminosity for Initial Operation	10^{33} cm^{-2}s^{-1}
Center of Mass Energies (ep)	20 GeV - 140 GeV
Proton Polarization	70%
Electron Polarization	80%
Detector forward acceptance:	
p_T acceptance	200 MeV/c – 1.3 GeV/c
forward neutron acceptance	4 mrad
Minimized construction and operational cost of the accelerator	